



# Implications of the Higgs discovery on minimal dark matter

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## Abstract

The existence of dark matter provides compelling evidence for physics beyond the Standard Model. Minimal extensions of the Standard Model with additional scalars or fermions allow to explain the observed dark matter relic density in an economic way. We analyse several of these possibilities like the inert Higgs and radiative seesaw models in the light of the recent Higgs discovery and study prospects for the direct and indirect detection of dark matter in these models.

## Keywords:

Dark matter, minimal models, Higgs boson

## 1. Motivation

Gravitational effects of dark matter have been observed in galaxies, clusters of galaxies, the large scale structure of the Universe and the cosmic microwave background radiation. These observations indicate that dark matter accounts for about 85% of the matter density in the Universe and for 23% of its total energy density. It must therefore be considered today to be one of the essential ingredients of our Universe.

Viable dark matter particles should be neutral, stable and weakly interacting, and, to be consistent with the observed large scale structure of the Universe, behave as *cold* dark matter. Since none of the Standard Model particles satisfies these conditions, dark matter provides strong evidence for new physics, and indeed most extensions of the Standard Model include dark matter candidates.

WIMP (Weakly Interacting Massive Particle) dark matter represents a generic scenario, that can naturally account for the observed dark matter density via freeze-out in the early Universe. Here, the dark matter candidate is a weakly interacting particle with a mass around the TeV scale - the same scale that is currently being probed by the Large Hadron Collider (LHC) at CERN.<sup>1</sup>

<sup>1</sup>Alternatively, the interactions of the dark matter particles could

## 2. Minimal models of dark matter

The idea behind minimal models of dark matter is to extend the Standard Model in a minimal way, so that dark matter can be explained. Typically, these models feature a small number of additional fields and a new discrete symmetry that stabilises the dark matter particle. They include models such as the inert doublet model [2], the radiative seesaw model [3], and the singlet fermion model [4]. The coexistence of two dark matter particles is yet another possibility that is currently being explored [5], as are coannihilations of dark matter and other particles [3, 6, 7, 8].

### 2.1. The inert doublet model

In this model, the Standard Model is extended with an additional scalar doublet,  $H_2$ , which is assumed to be odd under a discrete  $Z_2$  symmetry. The dark matter candidate is the neutral component of this new doublet ( $H^0$ ) and is then a WIMP featuring gauge and scalar interactions.

At the tree level (see Fig. 1), the  $q$ - $H^0$  scattering relevant for direct detection proceeds via a Higgs-mediated

also be so weak that they never reach thermal equilibrium, leading to a so-called freeze-in scenario [1].

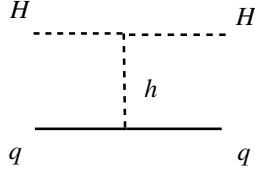


Figure 1: Tree-level Feynman diagram for the direct detection cross section of inert higgs dark matter.

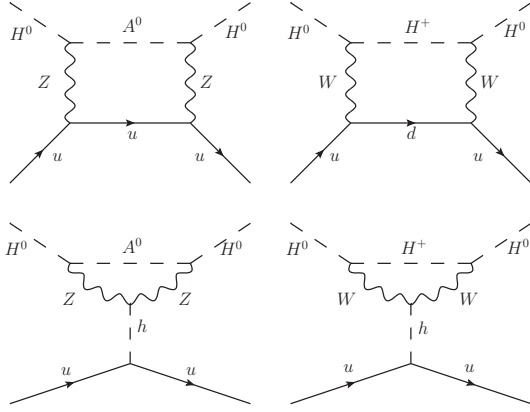


Figure 2: One-loop Feynman diagrams that give the dominant corrections to the direct detection cross section of inert higgs dark matter [2].

diagram and is determined by a scalar coupling. Following the recent LHC discovery of a Standard-Model like Higgs boson, we set  $m_{h^0} = 125$  GeV.

At the one-loop level (see Fig. 2), the spin-independent direct detection cross section receives new contributions from W- and Z-mediated diagrams which are determined by the gauge couplings. As a result, the one-loop contribution can actually dominate the direct detection cross section. In fact, it provides a lower bound on the spin-independent cross section that is within the reach of planned experiments such as XENON1T [9] (see Fig. 3) [2].

## 2.2. The radiative seesaw model

The radiative seesaw model is an extension of the inert doublet model by three singlet fermions  $N_i$  that are odd under the  $Z_2$ . Its Lagrangian includes the following terms:

$$\mathcal{L} = -\frac{M_i}{2} \bar{N}_i^c P_R N_i + h_{\alpha i} \bar{\ell}_\alpha H_2^\dagger P_R N_i + \text{h.c.} \quad (1)$$

The main feature of this model is that it can account also for neutrino masses. They are generated at one loop and

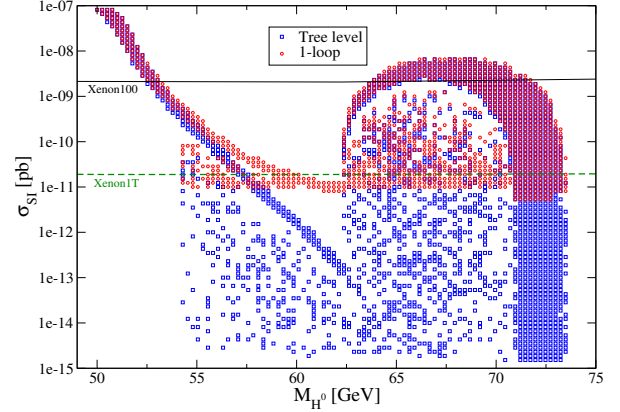


Figure 3: Scatter plot of the spin-independent direct detection cross section at tree-level and at one-loop as a function of the dark matter mass. In this figure all the parameters of the inert higgs model were allowed to vary randomly and all experimental bounds were taken into account [2].

are given by

$$(m_\nu)_{\alpha\beta} \simeq \sum_{i=1}^3 \frac{2\lambda_5 h_{\alpha i} h_{\beta i} v^2}{(4\pi)^2 M_i} I\left(\frac{M_i^2}{M_0^2}\right). \quad (2)$$

If some of the singlet fermions have a mass slightly larger than that of  $H^0$ , coannihilations with  $N_i$  become relevant and give rise to an *increase* in the relic density (see Fig. 4). The relic density thus strongly depends on the mass difference between  $H^0$  and the singlet fermions. The resulting indirect detection rate is large and provides a constraint on the parameter space of the model (see Fig. 5) [3].

## 2.3. The singlet fermionic model

In this model, the Standard Model is extended with a singlet fermion ( $\chi$ ) and a singlet scalar ( $\phi$ ), which are odd and even under a  $Z_2$ , respectively. The fermion is therefore the dark matter candidate and interacts via

$$\mathcal{L}_\chi = g_s \phi \bar{\chi} \chi + i g_p \phi \bar{\chi} \gamma_5 \chi. \quad (3)$$

The new scalar mixes with the Higgs boson, giving rise to the mass eigenstates  $H_1$  and  $H_2$ . The dark matter annihilates mainly into four different channels:  $W^+ W^-$ ,  $H_1 H_1$ ,  $H_1 H_2$  and  $H_2 H_2$  (see Fig. 6). As one can see in Fig. 7, some regions of the parameter space can already be excluded by direct detection constraints.

## 3. Summary

Using three different examples for minimal extensions of the Standard Model, we have illustrated in these

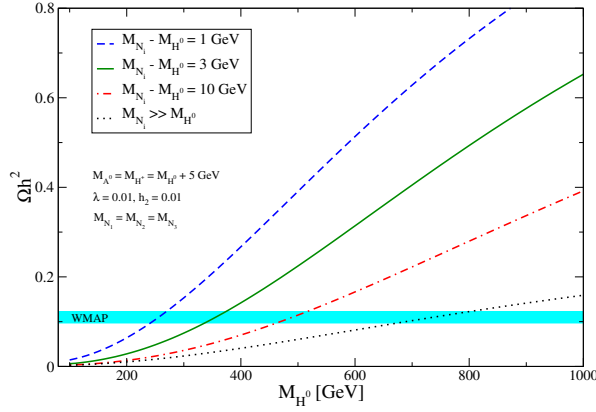


Figure 4: The relic density as a function of  $M_{H^0}$  for different values of  $M_{N_i} - M_{H^0}$ . In this figure we have set  $\lambda = 0.01$ ,  $h_2 = 0.01$ ,  $M_{A^0} = M_{H^\pm} = M_{H^0} + 5$  GeV and we have assumed that the three fermions have the same mass:  $M_{N_1} = M_{N_2} = M_{N_3}$ . Notice that  $\Omega h^2$  decreases with increasing  $M_{N_i} - M_{H^0}$  [3].

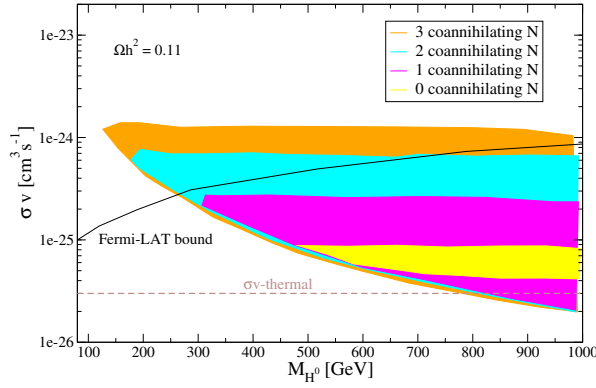


Figure 5: Regions in the plane  $(M_{H^0}, \langle\sigma v\rangle)$  that are consistent with the dark matter constraint for different numbers of coannihilating  $N$  [3].

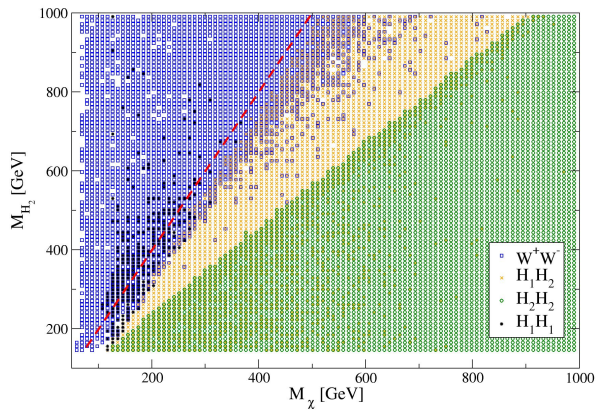


Figure 6: The region in the plane  $(M_\chi, M_{H^0})$  that is compatible with the dark matter constraint. Different symbols are used to distinguish the dominant annihilation final states. The dashed (red) line shows the resonance condition:  $2M_\chi = M_{H^0}$  [4].

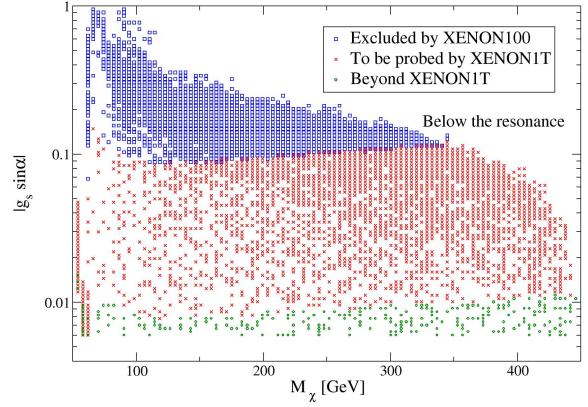


Figure 7: The reach of current and future direct detection experiments [9] in the singlet fermion model below the resonance [4].

proceedings the interplay of the Higgs boson discovery and dark matter relic density constraints and their implications for direct and indirect searches for dark matter.

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